How to Build a Customized Astrolabe Using a Laser Cutter

by JohnW539

What is an Astrolabe?

The astrolabe was the most advanced and complex device for timekeeping and making astronomical calculations during the Middle Ages. By modeling the motions of the stars, Sun, and planets, the astrolabe allows the user to predict the positions of objects in their sky at any time and date. At its heart, the astrolabe is a model of the universe that you can hold in your hand. It is an analog computer that tracks the motions in the sky.

The modern version of astrolabes were created by Islamic scholars during the 8th century, but the roots of this device go back to the ancient Greeks. By the 13th Century, any educated person in Europe would know how to use an astrolabe to do a variety of astronomical calculations. In fact, the first known technical manual in the western world detailed how to use an astrolabe. This manual was written by Geoffrey Chaucer for his 11-year old son. With smartphones and computers, we no longer need to use these beautiful devices to tell time or predict the positions of stars. However as Tom Wujec discusses in his Ted Talk, the technological we use shapes how we think about time. By building an astrolabe, we can connect to a sense of time and celestial motion that we cannot find with just a smartphone.

Beyond just being an astronomical device, astrolabes are works of art. Islamic and Western astrolabes are filled with beautiful engravings in brass. In museums like the Adler Planetarium and the Oxford Museum of the History of Science, the astrolabes on display show a blending of science, technology, engineering, art and mathematics. Astrolabes were a prime examples of STEAM from the Middle Ages.

Project Goals

The time to complete this project, including the customization steps, should be about 2 hours. The actual laser etching time is just under and hour using the 40W Epilog laser at my Makerspace. In this project, you will:

1. Construct a beautiful astrolabe out of acrylic (or another similar material) using a laser cutter.
2. Align your astrolabe to the current time and date so you can calculate the position of bright stars in the night sky.
3. Understand how to create cutting templates for the laser cutter using Adobe Illustrator.

How to complete this project

Depending on your level of expertise and interest, there are three basic options for completing this project:

- **The basic astrolabe** - Skip steps 2, 3, 4, and 6. Just use the "front_back_london.ai" file instead of making a custom astrolabe for your location. This involves NO editing of the files. You just download the files, send them to the laser cutter, and assemble the astrolabe. It will look just as cool as one customized for your location, but it involves many fewer steps. You can also just the "mini_astrolabe.ai" file and just send it to the laser etcher on a single piece of acrylic.

- **A customized astrolabe for your location** - Do all the steps except the optional step 11. This will let you create a customized astrolabe for your location. It does involve downloading the astrolabe generator software, creating some eps files, the then incorporating them into an etching template I provided. It isn't all that hard to do these steps if you are patient and follow the instructions through the process.
- **The full astrolabe experience** - Do all the steps, including the optional steps #11. By doing all the steps, you will create your creating very own astrolabe rete and customized astrolabe. You will how to change an Adobe Illustrator file into an etchable template by doing this, but it involves a more graphic design elements.

You might want to try building the basic astrolabe first, and then build a customized version later. It's up to you, but let's get started!

Step 1: Gather Your Construction Materials

Purchasing your materials at the hardware store
The first step in this project is to gather the materials you need to construct your astrolabe. The total cost for all the parts for this project is about $25. There are a few design choices here, but I will go through the materials that I used to make my version of this project.

From your local building supply store, you should purchase the following things:

- Sheets of clear 11x14 inch Acrylic sheets with a thickness of 0.093 inches (1/8 inch). *You need two sheets the full-size astrolabe and one sheet if you wish to make a set of three mini-astrolabes.*
- A small bag of locking nuts for #6x32 machine screws
- A small bag of washers for #6x32 machine screws
- A small bag of #6x32 machine screws ¾ of an inch long
- A small bag of #6x32 machine screws, ½ an inch long

For this project, you only need one ½ inch screw, one ¾ inch screw, two locking nuts, and four washers . If you like, you could use brass screws and Locktite in lieu of the lock nuts.

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The acrylic sheets for the project can be found in any big box building supply store which sells glass for replacement windows. (I got my acrylic at the local Home Depot.) If you like, you can use any laser etchable and cuttable material for this project. Using the colored acrylic would give the astrolabe a more classic look. However making a wooden astrolabe out plywood also would produce beautiful results. As a bonus, the acrylic sheets are also very inexpensive. No matter what material you decide to use, make sure it is safe to burn in the laser cutter.

Adding color to your astrolabe
From your local office supply store, purchase one set of colorful plastic notebook dividers. You will use these to add color to the final project. This color helps increase the contrast of the writing and marks on the astrolabe against the transparent acrylic. You could use a piece of colored construction paper if you wish, but I really like the translucent look of the device with the colored plastic. If you are using the colored acrylic or wood for the front and back of the astrolabe, you wouldn't need this material.

You will also need:

- A laser cutter capable of cutting and etching 1/8 thick acrylic.
- A computer that runs Adobe Illustrator and Java.
- A Screwdriver and wrench to tighten the nuts.

The laser cutter is the ideal tool for the project. The fine etching and precise lines can't easily be done any other way. You may be able to do this project using Corel Draw with the Adobe files, however I haven't experimented with this.

Now that you have your materials, we are ready to get started! Since you probably want to customize the astrolabe to your location, the first thing we need to do is figure out your latitude and longitude. If you don't want to customize your astrolabe, skip to step 5.

Step 2: Determine Your Exact Location - or the Exact Location for Your Astrolabe.

Where are you?
When you construct and astrolabe, you are building a device to calculate the time based on the stars. In the Middle Ages, astrolabes had a "mater" (holder) and "plates" (a set of grids set to local positions) which allowed the user to change the location as they travelled. For our design, we are going to construct an astrolabe that works at a single location. To do this customization, you need to know determine your latitude and longitude.

The great website to determine your latitude and longitude is:

https://www.latlong.net/convert-address-to-lat-long.html

When you enter your address, you can immediately get your precise longitude and latitude.

In the example in the image for this step, I set the address to:

1300 East Main Street, Murfreesboro, TN 37132

At the bottom of the screen, the GPS coordinates are listed as

35° 50' 36.5424"N

86° 22' 15.24" W

We will use this location in the next step to customize the astrolabe using the great software created by Richard Wymarc. The software calculates the front and back of the astrolabe based on these two number, but they have to be entered in the correct format. For the position in our example, we would set the location to:

355037N 0862215W

The leading zero in the longitude is needed for the formatted read being used. Now that you have YOUR location, let's download this software!

Step 3: Download Richard Wymarc's Astrolabe Software

Downloading the Astrolabe Software
As I mentioned in the last step, Richard Wymarc has created an excellent free software package for creating astrolabes. His intent was to make astrolabes you could print on paper or transparent film. The output of his program is a set of four Encapsulated Postscript (eps) files. He has worked on this project as a labor of love for years, and his results are both beautiful and accurate. I must note that the paper versions of the astrolabes his software produces are great! If you are doing a school project and need to make a bunch of these, they are an excellent option.

Because such great software is available, the primary focus of this Instructable is to show how to take these

eps files and convert them into a format that can be used by a laser cutter. Since astronomy is my day job (and sometimes night job too), I thought seriously about making my own astrolabe generator for this Instructable. Fortunately, I didn't do this. His software is perfectly suited for this job.
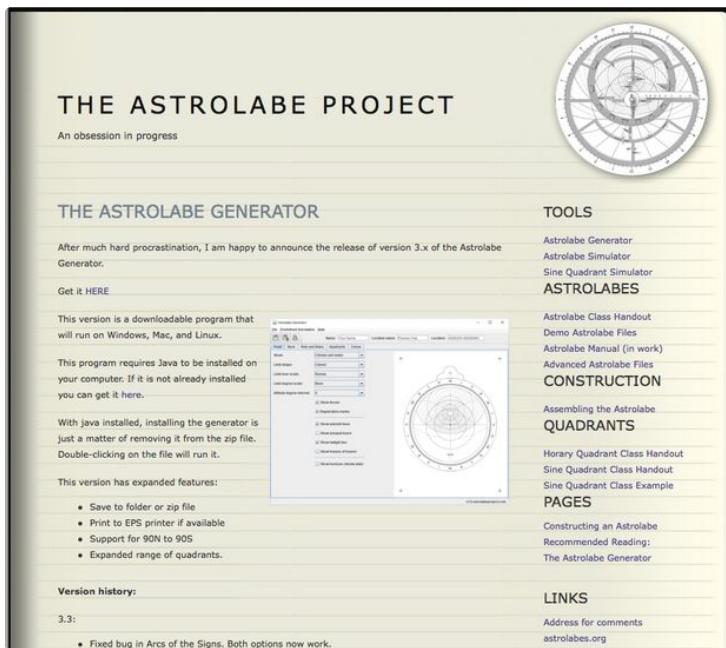
You can download his software from his website:

http://www.astrolabeproject.com

The direct link to the download is here:

http://www.astrolabeproject.com/category/astrolabegenerator/

## Step 4: Use the Software to Generate EPS Files for Your Astrolabe

Create the EPS templates for the Astrolabe
Creating the EPS files for the project is very straight forward.

1. Create a folder that you will use to store the files for your project.
2. Run the software. Since this program was written in Java, you will need to have Java installed on your computer. For linux and Macintosh systems, you can run this from a command line: ***java -jar AstrolabeGenerator-3.3.jar***

   However, double clicking the program icon will also work once you let the computer security settings know that this code is allowed to run on your computer. Here is a guide to running Java "jar" files on Windows computers from Stack Overflow.

3. Set your name, location name and location in the program. The location and your name will appear on the back of the astrolabe, so you may want to customize this if you are making this as a gift. Of course use the results from the last step to type in your latitude and longitude.
4. Save the files to your folder. Generally this will save a zip file named astrolabe.zip. Once you unzip this file, you will have four new EPS files in your directory:
   - AstrolabeBack.eps
   - AstrolabeRules.eps
   - AstrolabeRete.eps
   - AstrolabeFront.eps

5. You will only need to use the AstrolabeFront.eps and the AstrolabeBack.eps files for this Instructable. I used the AstrolabeRules.eps and AstrolabeRete.eps files to create one of the Adobe Illustrator files you will use later in the project.
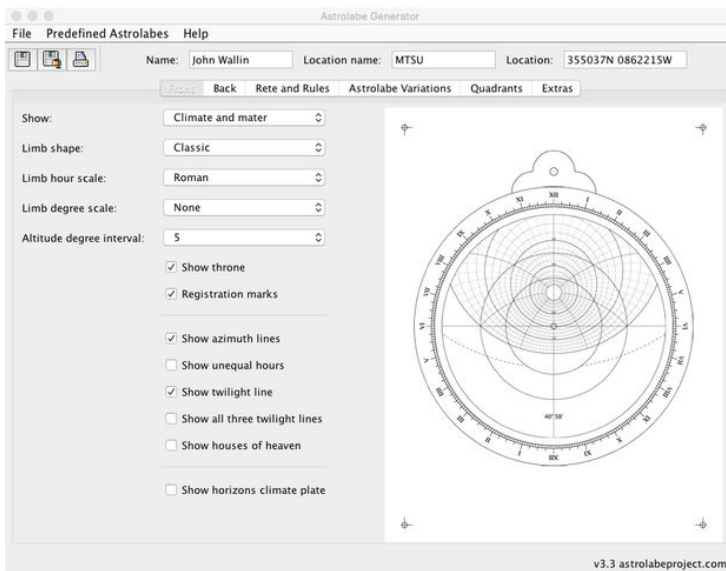
Step 5: Download the Adobe Illustrator Files for This Project.
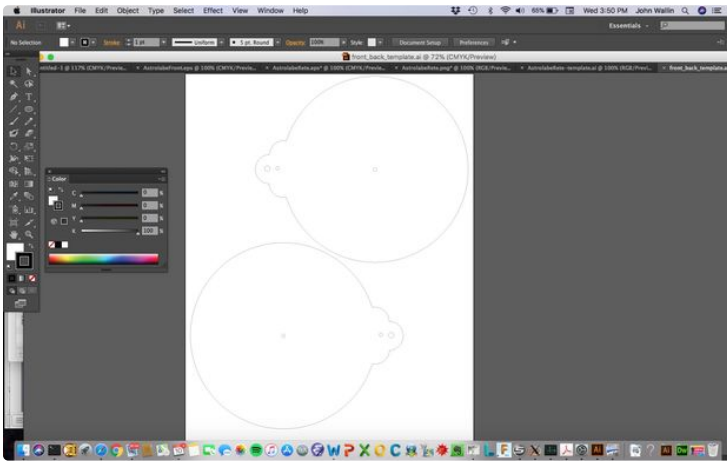
Download the templates
I have created four Adobe Illustrator files to make this project a bit easier for those new to using laser cutters.

They are:

- **avery_circles.ai** - a ready to etch pattern for cutting the color disks that fit between the front and back of the astrolabe.
- **avery_circles_mini.ai** - a ready to etch pattern for cutting the color circles for the mini-astrolabes
- **front_back_london.ai** - a ready to etch front and back of an astrolabe (set for Greenwich Observatory, London) that you can use without any software or editing.
- **front_back_template.ai** - a template for making your personalized astrolabe.
- **mini_astrolabe.ai** - a ready to etch set of 3 mini-astrolabes that fit on a single piece of 11x14 acrylic.
- **rete_and_stand.ai** - a ready to etch the rete (the mesh work with the locations of the stars and ecliptic) and a stand for the astrolabe.

Download the zip file to your computer, and then unzip it. Now you have a choices to make:

1. If you just want to make some cute mini-astrolabes, you can use the two "mini" files from above. The "mini_astrolabe.ai" file will give you three mini-astrolabes out of one sheet of 11x14 acrylic. The "avery_circles_mini.ai" file will give you enough background circles for this project from a single piece of the plastic dividers. These mini-astrolabes are set for the latitude and longitude Greenwich Observatory in London. You can skip to step 8.
2. If you want to make a full size astrolabe, but you don't care about customizing it, you can use the "front_back_london.ai", the "rete_and_stand.ai", and the "avery_circle.ai" file and skip to step 8.
3. For customizing the astrolabe to your location, just follow the next steps.

Step 6: Edit the Astrolabe EPS Files for the Front and Back of the Astrolabe.

Put the Customized EPS files into the Cutting Templates

The front of the astrolabe contains an etched grid that allows you to determine the location of stars in the night sky at a particular time and on a particular day. The positions of stars are measured locally in terms of their altitude (angle above the horizon) and their azimuth (the compass heading). As time passes, the altitude and azimuth of stars changes because of the Earth's rotation.

The altitude and azimuth of stars also changes when you move to different locations on Earth. Because of this, we need to generate a new astrolabe front for every location. You can customize this as much or as little as you want to. Although you need to enter the latitude and longitude of your position down to the arc second in the software, realistically you might determine the positions of stars to an accuracy with this device of better than about a degree if the device is correctly aligned.

The back of the astrolabe contains a number of different scales we use for measuring the altitude of stars, determining the location of the Sun throughout the year, measuring the length of shadows based on the Sun's altitude, calculating time using the medieval concept of unequal hours, etc. The software Richard Wymarc wrote creates a customized back with your name, location and position.

If you get confused in these steps, take a look at the "front_back_london.ai" file or the "mini-astrolabe-11x17.ai" file. This example file shows how the final drawing should look when you are done.

1. Open the "front_back_template.ai" file in Adobe Illustrator.
2. Import the "AstrolabeFront.eps" file you created from the AstrolabeGenerator softwares in two steps ago into Adobe Illustrator into a new Illustrator window. We will be making some modifications to this graphical element before we merge it into the template.
3. Using the arrow tool and the mouse, select everything in the frame.

4. Under the object menu, select "Ungroup".

5. Use the arrow tool to select the outer transparent frame, and delete it with the delete key.

6. Select the registration mark using the mouse tool. This will also include the "crown" of the astrolabe from the EPS file. Delete the registration marks and the crown.

7. Select everything.

8. (OPTIONAL) You MAY wish to change the point size of all the lines to 2. This darkens the lines for the etch and makes it a bit easier to read. You can also modify the fonts to a different type to make the etched acrylic a bit easier to read. These changes aren't critical. You also might wish to add other graphical elements to the design. If you want to add "Happy Birthday!" with a large picture of a llama, this is the time to do it. If you do customize the project, try to avoid adding more elements to the altitude-azimuth grid so you can still track the stars!

9. Select "Group" under the Object menu.

10. Rotate this object by -90 degrees by selecting Object->Transform->Rotate.

11. Copy this object using the Edit->Copy.

12. Go back to the "front_back_template.ai" window. Paste the object with the the modified astrolabe front from your buffer into this template (Edit menu -> paste).

13. Move this object to the back of the drawing using Object->Arrange->Send to Back.

14. Move the astrolabe front you just pasted into the document so it is aligned with the bottom template. There should be a small space between the template and the Front.

15. Repeat steps 1 through 14 with the back of the astrolabe with two modifications:
    1. Rotate the astrolabe back by +90 degrees, not -90 degrees in step 10.
    2. Align the astrolabe with the upper template.

16. Use the "Save As" option to save this as "astrolabe_front_and_back.ai". You can close the EPS files if you wish at this point.
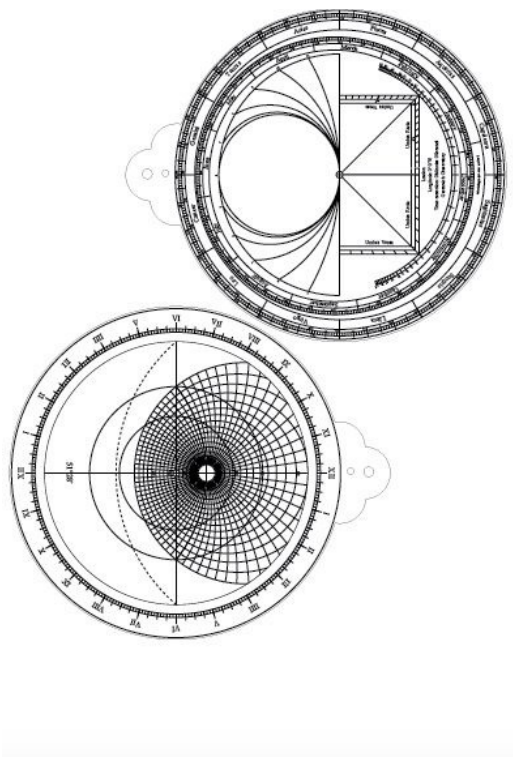
Step 7: The Rete of the Astrolabe, the Rule, the Alidade, and the Stand

The other pieces you need to engrave and cut for the project are the Rete, the Rules, the Alidade, and the Stand for the Astrolabe. Since all of these elements don't change between locations in the northern hemisphere, you can use the "rete-and-stand.ai" file I provided for this part the project. If you live in the southern hemisphere, you will need to do some customization of the project. Jump to optional step 11 if you need to make a custom rete.

Here is a short summary of these parts and their function:

- The rete of the astrolabe is used to represent the positions of stars in the night sky. Because the early astrolabes were made of brass, they used a lattice framework with arrows to point to the location of stars. In the standard version of the astrolabe produced by Richard Wymarc's software, this characteristic shape is produced. I think this lattice work is the coolest part of this project, but you can use the "Modern Rete" option from his software and put it on a transparent disk if you wish. If you do this, you will need to just make a simple cutting circle around the modern rete so the laser cuts out the correct parts of the plastic.
- The alidade of an astrolabe is the pointer on the backside of the device that is used to determine the angle a star has above the horizon. It is also used to determine the Sun's location in the ecliptic.
- The rule of an astrolabe are the straight pointers used on both sides of the device to make sightings of the stars and align the device to the correct times. Rules often have degree markings on them to determine the astronomical declination of objects. For this template, there are actually two rules (with the measured degree marks) and two Alidades.
- You only need one rule and one alidade for this project, but I put in a couple extra because there was plenty of room on the 11x14 piece of acrylic.
- The stand is just a simple acrylic stand to display this project.

If you want to learn how I made the cutting template for the Rete, take a look at the optional instructions in step 11. If you are in the northern hemisphere, you don't need to do this. However, I thought adding this step might be helpful for people wanting to make cutting templates around vector graphics in Adobe Illustrator.
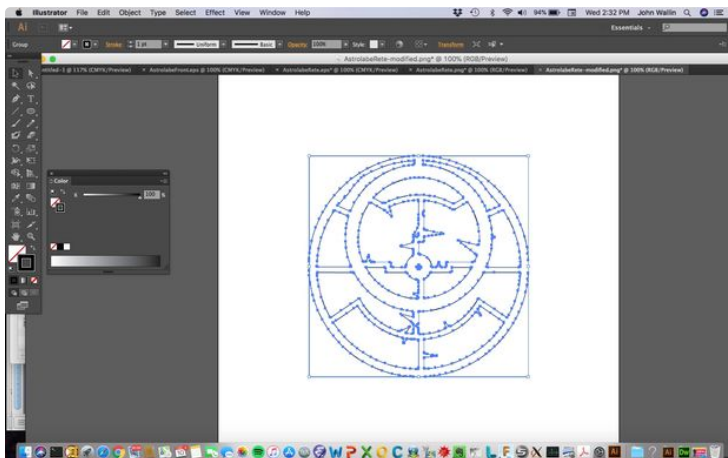
Step 8: Etching and Cutting the Parts

You should have two files that are ready to be etched:

- rete_and_stand.ai
- astrolabe_front_and_back.ai

These are both ready to be sent to the Laser Etcher. Let's start with the rete_and_stand.ai file.

Set up the acrylic and the machine
Here are the first steps:

1. Turn on the laser system. You may wish to run a piece of scrap material in the laser etcher with a small test pattern to make sure the laser is warmed up.
2. Take the plastic cover off of the first 11x14 piece of acrylic.
3. Place the acrylic in the laser etcher.
4. Zero the home location of the laser to the upper left hand corner of the acrylic.
5. Focus the laser. I prefer to use the manual focus setting, but this is entirely up to you..
6. Close the top of the laser etcher.
   -

Set up the print job
In general, you just need to do the basic settings recommended for 1/8 thick acrylic. I used the following settings with our Epilog 40W Helix system:

1. Go back to your files in Adobe. Select print from the file menu.
2. Go to the setup menu so you can adjust the laser settings.
3. Set the document size to 11x17 inches. The actual acrylic size is 11x14, but this was not a standard setting available in my print menu. I set the art boards to 11x17 to match this setting, but just kept the design with in the 11x14 inch limits of the acrylic.
4. Set the Job Type to Combined
5. Set the resolution to 300 or 400 DPI.
6. Set the Dithering to Stucki
7. The raster settings were set to a speed of 90 and a power of 75 for my laser etcher, but use the settings recommended for acrylic for your matching.
8. The vector settings were set to a speed of 12 and a power setting of 100 for my etcher. Again, use the settings recommended for your machine.
9. Click ok on the settings dialog box, then press print to send the file to the laser etcher.
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     (Note: the raster setting hasn't been adjusted yet. Make sure to use the settings for your machine.)

The laser etcher should be ready to go! Press print to send the file to the laser etcher.

Etch the Acrylic
1. Make sure the file has arrived in the laser etcher.
2. Turn on the air compressor that is used to suppress any flames from cutting.
3. Make sure to turn on the air filtration system. Acrylic is stinky!
4. Press GO!
   -

It should take about 20-30 minutes to etch these file using an Epilog 40W laser. When it is done, let the smoke clear through the filter before you open the etcher. Remove the parts and the waste from the etcher.

Repeat the steps with the "astrolabe_front_and_back.ai" file.

Cut the plastic divider sheets using the Laser
As a final step, open the "avery_circles.ai" file in Adobe Illustrator. Load a piece of the Avery plastic divider into the laser printer. Zero the XY on the upper left hand corner, and focus on the sheet. I used a laser speed of 100 and a power setting of 30 for the 40W Epilog system I used at my Library's Makerspace. You will want to cut two piece of plastic with pleasing colors. These will be sandwiched between the front and the back of the astrolabe.

Step 9: Assembling the Astrolabe

Putting it together

Assembly the astrolabe is really easy. You should have a pile of plastic pieces from your laser etching, two thin pieces of Avery plastic dividers, and the #6-32 hardware you purchased.

The order to put the pieces in is:

- The Rule (the pointer with the markings on it)
- The Rete (the spidery assembly with the star positions)
- The Front
- The two pieces of Avery plastic
- The Back
- The Alidade

This diagram shows the order of assembly. Make sure you can read the text is facing outward for each piece so it is readable.

Use one of the 3/4 inch screws and a locking nut for the center hole. You may wish to use one washer in between the screw head and the plastic and the locking nut and the plastic. You want to tighten the screw just enough so that the rete, the rule, and the alidade all rotate smoothly with a gentle push of your finger but stay in place when you let them go.

Use a 1/2 inch screw, two washers and a locking nut in the lower hole in the crown. The front and back of the astrolabe should not rotate when your turn the rete, the rule, or the alidade.

At this point, you may wish to attach a lanyard through the top hole the crown of the astrolabe. It is helpful to be able to suspend the astrolabe when you are taking sightings of stars. You can also where they astrolabe around your neck and make a bold fashion statement.

Assembling the parts of the stand is easy. Just put them together using the slots in the plastic pieces. You may wish to make a lighted stand for this project. I thought it was a bit outside the scope of this Instructable, but the resulting backlight astrolabe would look awesome!

The resulting astrolabe should look like the pictures at the top of this section when it is fully assembled.

Step 10: Aligning Your Astrolabe With the Universe

The Planisphere
To understand how the astrolabe works, it is easier to start out with the astrolabe's great grandson - the planisphere. Long before smartphones and computers were used to create digital star maps, this modest device was used by millions of amateur astronomers to identify the stars in the sky. You can still find them for sale, and they are still a great way to learn the names of stars and constellations. If you want to build your own planisphere, there is an Instructable on constructing a Starwheel for Backyard Astronomy that will teach you how.

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To use a planisphere, you need to just align your current date in the outer ring to the current time on the inner ring. In the picture, you can see that the device is set for January 13 at 9pm. You can see that the astrolabe is also aligned to work on January 28 at 8pm and February 13 at 7pm.

We normally measure the length of a day by Earth's rotation as measured with respect to the Sun. The Earth, however, orbits around the Sun. Because of this, the rotation of the Earth measured with respect to the stars takes about four minutes less than the rotation of the Earth as measure with respect to the Sun. This means that stars we saw in the sky at 8pm 15 days ago are in the sky at 7pm. The planisphere accounts for this by having both a time and a date ring. By aligning these two rings, you can set the stars to the right position for any time during the year.

The stars that appear in the oval window are the stars that appear in your local sky. If hold put the device above your head, the star positions on the map align with the locations of the stars in the night sky. The edge of the oval window represents your local horizon. The center of the oval window (not the rivet at the center of the planisphere) is the zenith - the point directly above your head. If you want to look at stars near the northern horizon, you need to have the word North pointing towards you like in the diagram below.. In the picture below, you can see Ursa Major (a.k.a. the Big Dipper) is tilted upward just to the east of North.

The rivet that is at the center of the planisphere represents the point directly above the north pole of Earth. This is called the North Celestial Pole. Because of this unique location, stars appear to rotate around it during the night. The star nearest to it is Polaris (a.k.a. The North Star). This star remains fixed directly above due north at all times. If you can find Polaris, you can find North.

Planispheres are usually created for some range of latitudes. The one in this photograph was set for the range between 35 and 45 degrees North Latitude. For getting a general idea of what is in the sky, this kind of accuracy is fine.

The Astrolabe
The astrolabe works in nearly the same way as the planisphere. Just like the astrolabe, you need to set the time and date to align the positions of the stars. However with the astrolabe we need to take one additional step. Before setting the time, you need to find the location of the Sun in the sky. Here are the steps to align your astrolabe:

1. Go to the back side of the astrolabe. When you align the alidade to the current date, you can determine where the Sun is in the Zodiac. In the picture below, I aligned the center line of the pointer to January 13. We can see that the Sun is 22 degrees into the constellation of Capricorn.

2. Flip the astrolabe over and hold it by the crown. Find the circle on the rete that represents the ecliptic. This circle is labeled with constellation names, but also has a degree setting within each constellation. This ecliptic is the annual path of the Sun through the stars during the year. This apparent motion is actually caused by the Earth orbiting the Sun. Up to Copernicus, this motion was understood to be the actual path the Sun travelled in its yearly journey through the background stars.

3. Align the rule of the astrolabe to the position of the Sun on the ecliptic circle. For our example, I put the rule on 22 degrees in the constellation of Capricorn.

4. Now move the rule and the rete _together_ so the rule points to the correct time. Noon is at the crown of the astrolabe while midnight is located directly opposite of the crown. The Roman Numerals tell you the time. In our example, I've set the time to 9pm.

Congratulations, your astrolabe is now aligned with the Universe!

Determining positions of the stars.
The underlying grid in the astrolabe allows you to determine the precise location of stars. This grid is very similar to the giant oval window on the planisphere, but it is calibrated with angular markings for your location. The outer level of the grid is the horizon. The center of the grid is the zenith, the point directly above your head.

Just link with the planisphere, the rotation point represents the location of the North Celestial Pole and the star Polaris. Everything rotates around this point because of the daily rotation of the Earth.

If you look near the sharp points in the rete, you can see star names or at least the abbreviations of the stars. In the picture, you can see the point with the letters "Aldeb" next to it. The spike next to "Aldeb" represents the position of the star Aldebaran, the star at the eye of the bull in the constellation of Taurus. Each of the circles in the grid is 5 degrees apart. You can see a scale printed on the grid with the numbers 40 and 60. Those represent the circles of positions 40 and 60 degrees above the horizon respectively. Using this grid we can see that the star Aldebaran is located 10 degrees above the 60 degree circle, or about 70 degrees above the horizon. We can also determine the azimuth or compass heading of objects. North is toward the crown of the astrolabe, east is to the left side, and so on. Because of the type of projection being used, these directions are backwards compared to the Planisphere.

We can also use the back side of the astrolabe to verify the altitude of the astronomy Aldebaran. First, you need to go outside and find the star in the sky. To make the altitude measurements accurately, you need to suspend the astrolabe by its crown on in sure it is being held vertically. The hole in the top of the crown is designed to hold a string, cord, or rope for this purpose. You then use the alidade to site the star and read the angle off of the scale on the back. Since the Sun's path is divided into exactly 12 constellation along the ecliptic (known as the Zodiac) and each constellation spans exactly 30 degrees, you just need to use the outer scale of the device to determine this angle. One of the amazing things about this device is you can work this process backwards and use the position of astronomical objects to determine the time. Instead of knowing what the time is, you can do a sighting of a star to determine its altitude, and then place it in the correct location on the grid. By using the rule, you can figure out what the time is if you know the current date.

Because the astrolabe was originally made of brass, there are only about 20 stars on the rete. If you were an educated 11 year old in the 13th century, your father would make sure you knew the names of these stars and knew how to find them in the night sky. The planisphere does allow you to see more objects, but the grid of the astrolabe and the ability to do sightings make it a more precise instrument for determining time or making astronomical calculations.

There is no practical reason to own an astrolabe in the 21st century. Smartphones can tell us the time to the millisecond. We can even use their internal GPS and positions sensors to identify the stars we see in the sky. However, astrolabes create a physical model of the universe that we can hold in our hands and manipulate. They are really fun to build. Besides, practical isn't everything.

Other Resources
These instructions barely cover the basic function of the astrolabe. There are some great external resources to learn more how they work and how to use them. Here are a couple good places to learn more:

- Tom Wujec's TED talk on Astrolabes

- Richard Wymarc's Astrolabe Project site
- James E. Morrison's Astrolabe site
- Astrolabe - The Missing Manual by Timothy Mitchell
- Chaucer's Treatise on the Astrolabe

Enjoy your astrolabe!
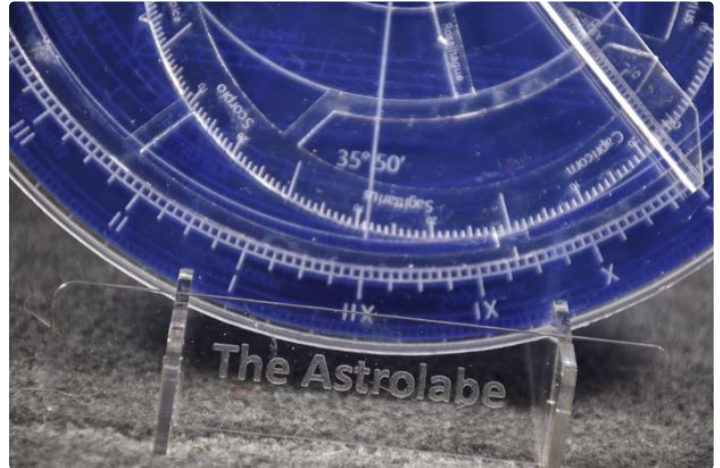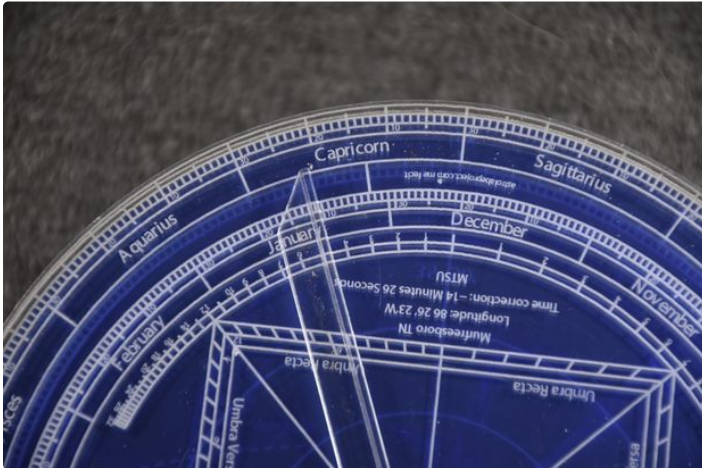
Step 11: Optional Instructions: How to Create the Cutting Template for the Rete

Most people will not need to make a customized rete. The rete I made using the template from Richard Wymarc's software will work for any astrolabe in the Northern Hemisphere. If you live in the southern hemisphere or you want to design your own rete, I thought it would be helpful to detail the steps I used to create it. This same set of steps here can be use to etch around any Adobe Illustrator file. ***Remember, these are OPTIONAL steps!***

Laser cutters can both etch and cut materials. For Epilog laser systems, the software is designed to etch any graphical vector graphical elements with a "hairline" or "0.01 pt" width. Other vector or bitmap elements are etched instead of cut into the material. To make a design that is both etched and cut, you need to separate the outline you want to cut into vector elements with a width of 0.01pt and combine it with the original image.

The basic way we make an etching template in Adobe Illustrator for this project is to turn the EPS image into a bitmap. From the bitmap, you can silhouette the image and then modify it so it is a bit stronger in a few select places for when you cut the acrylic. From this modified bitmap, you can trace an outline of the rete. You then combine the rete outline with the original modified eps file so the cutting outline is merged with the etching outline.

1. Import the EPS file into Adobe Illustrator.
2. Select everything in the frame, and ungroup them.
3. Select the outer transparent frame, and delete it.
4. Select one of the corner registration marks, delete it as well.
5. Select everything, and then group it.
6. Export this image as a file named "rete.png". Keep this at 300 DPI with transparency. To do the image tracing in Illustrator, we need to use a bitmap file rather than a vector file. This step exports the image as a bitmap file.
7. Open "rete.png" into a new window. This will import the file as a bitmap image rather than a vector image.
8. From the top menu, select from "Image Trace" the "Silhouette the image" option. This will convert the image into a black outline of the original rete.
   □
9. Since the top of the rete comes together into sharp points, it helps to strengthen this part of the plastic. Do this by creating a circle of the same size as the astrolabe – I created a circle with 427 pixels x 427 pixels with a size of 9 points in width.
   □
10. I used the alignment features in Illustrator to make sure it was on-top of the original bitmap file. The image below shows the graphics after horizontal alignment.
    □
11. Because this is now an image mixed between vectors and bitmap, you need to export this again as a PNG image. I used the name "rete-modified.png".
    □
12. Once again, read the "rete-modified.png" file into Adobe Illustrator.
13. From the Object menu, select Image Trace -> Expand.
    □
14. Select the fill of the object, and turn it into empty/null.
    □
15. Select the outline, turn it to black and then set the width of the lines to 0.01pt.
    □
16. Select everything, and then group it.
17. Go back to the original "AstrolabeRete.eps" image. Ungroup everything, and the systematically eliminate any graphical element that is colored grey. Make sure you don't delete the marker lines or labels. Group this when you are done, and copy it into your buffer.
18. Paste the edited rete back in the frame where you created the outline. Move this image to the back layer.
19. Align the rete EPS image vertically and horizontally with the outline. You now have a vector image with a width of 0.01 pt for the cutting along with another vector image that will be used for etching.

Of course, you don't need to do this - that's why I provided the template!